

AIRBAG DEPLOYMENT AND OCULAR INJURIES OF OCCUPANTS

Takahiro Nakai

Ken Suzuki

Tomohiro Tobari

Hiroki Takahashi

Graduate School of Keio University

Naoyuki Suzuki

Ryoji Nakahama

Mitsubishi Motors Corporation

Yuuichi Takizawa

Hiroo Yabe

Toho University, Department of Ophthalmology

Kunihiro Takahashi

Keio University, Department of Mechanical Engineering

Japan

Paper Number 141

ABSTRACT

The relationship between ocular injuries and airbag deployment is studied experimentally in airbag deployment tests using pig eyes in vitro and newly developed load cells mounted on a fixed plate. Experiments conducted under various conditions reveal relationships between impact pressures on corneal surfaces and ocular injury rates. The ocular injury rate is determined by microscopic observation as the density of corneal endothelial cell loss. The relationship between impact pressure and injury rate is discussed statistically. No serious injuries to corneal endothelial cells occurred during the experiments within the framework of our test conditions.

INTRODUCTION

Airbag systems are widely recognized as effective safety devices, and have been proven to reduce serious injuries in automobile collisions [1-2]. However, studying the potential for ocular injury caused by airbag deployment is important [3-7]. Although airbag-related ocular injuries have been studied in the past, the relationship between ocular

injury and impact pressure has not been shown clearly.

The present study investigates the relationship between corneal endothelium injury and impact pressure caused by airbag deployment. The airbag folding pattern is also examined in order to determine the influence of folding pattern on impact pressure.

METHOD OF EXPERIMENT

Evaluation of Ocular Injuries and Measurement of Impact Pressure

The relationship between ocular injury and impact pressure caused by airbag deployment is investigated in the experimental study. In order to express the relationship, ocular endothelial injuries and impact pressures are measured precisely. The relationship between corneal endothelium injury rates in pig eyes and impact pressures can be obtained by exposing pig eyes implanted in a fixed flat plate to a deploying airbag on a test stand. Four pig eyes in vitro and twelve load cells are mounted on the surface of the fixed plate, enabling simultaneous evaluation of ocular injury and impact

pressure. In this study, the corneal endothelium injury rate of a pig eye is used for evaluating ocular injury.

From these experimental results, the relationship between corneal endothelium injury and impact pressure can be obtained quantitatively.

Experimental Equipment Using Fixed Plate

Figure 1 shows the test stand for the airbag deployment. The fixed plate is equipped with pig eyes and load cells. The distance d between the steering wheel and the fixed plate is set as $d=300\text{mm}$ or $d=220\text{mm}$. The condition $d=300\text{mm}$ approximates the contact position for an AM50 driver in the neutral seating position for a 50 to 55km/h barrier crash test. The condition $d=220\text{mm}$ approximates the contact position for an AF5 driver in the full forward seating position for a 50km/h barrier crash test.

In all tests, the plate remains stationary throughout the test. Since our purpose is to obtain the correlation between ocular injury and impact pressure, occupant movement during collision is considered to impart a small effect to the correlation itself.

Positions of four pig eyes and twelve load cells are shown in Figure 2. The position of a pig eye at point “A” coincides with the longitudinal center of the steering column. Figure 3 shows four pig eyes and twelve load cells arranged according to the placement depicted in Figure 2.

Each pig eye is surrounded by the four load cells. The injury rates of the pig eyes are assumed to correspond to the average of impact pressures measured by the four surrounding load cells. Using this method of measurement, the relationship between corneal endothelium injury and impact pressure can be derived quantitatively.

Placement of Pig Eyes

In this study, pig eyes in vitro are used for airbag deployment tests. A pig eye is approximately



Figure 1. Experimental equipment.

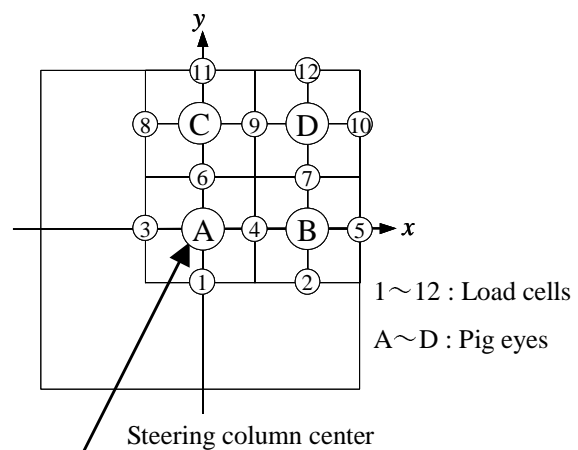


Figure 2. Positions of pig eyes and load cells.

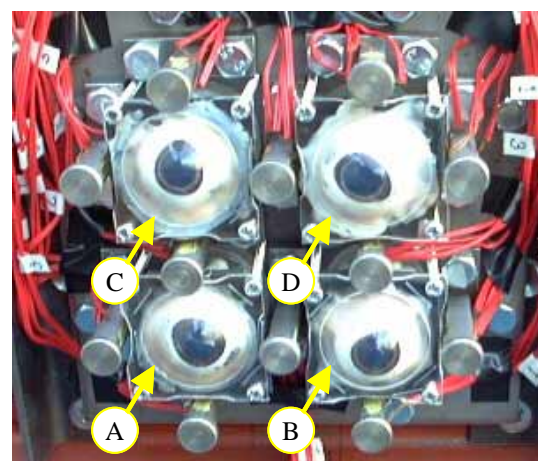


Figure 3. Arrangement of pig eyes and load cells.

equal in size to a human eye and is available comparatively readily. Pig eyes for the tests are used within 12 hours of slaughter and within 10 hours of removal. In order to prevent unexpected injuries, a protective ointment is applied to the cornea, and the pig eyes are refrigerated until just before the test.

In order to increase reproducibility, pig eyes are individually fixed to artificial orbits. An artificial orbit provides a constant boundary condition with a rigid backside mounting. Each artificial orbit consists of an acrylic cylinder, and a circular backboard.

Figure 4 depicts the method for locating a pig eye. Surrounding tissues of the pig eye such as cartilage, fat, and optic nerve are removed. Muscles are fixed with pins to the artificial orbit. A number of steel balls are packed densely in the cylinder from behind the pig eye, and steel balls are fixed to each other by use of quick-drying adhesive.

Each pig eye has individual difference in its original shape and size. By use of steel balls, all pig eyes can be placed under the same conditions, regardless of shape or size. A backboard is finally attached at the bottom of the cylinder. Following this procedure, soft tissues of an eyeball are covered and supported firmly, and the required boundary condition can be met.

RESULTS OF EXPERIMENT

Impact Pressure and Injury Rate

Figure 5 shows the transition of impact pressure for the case where the distance d between the steering wheel and the fixed plate is 220 mm. Impact

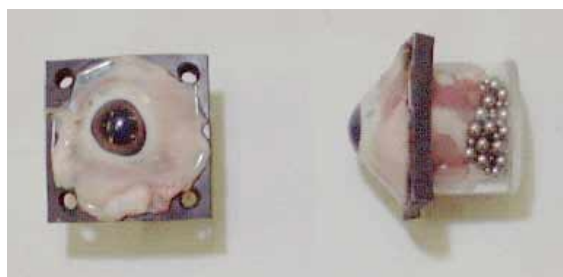


Figure 4. Pig eye and artificial orbit.

pressure measured by one of the load cells is shown in this figure. As shown in Figure 5, two peaks are observed. The first peak appears just after the first airbag contact with the load cell, and is defined as 1st peak impact pressure. The 1st peak impact has quite a short duration. As compared with the 1st peak impact pressure, the 2nd peak impact pressure has longer duration. Under the present condition, 1st peak impact pressure values tend to be higher than 2nd peak impact pressure values.

In order to evaluate ocular injury, the corneal endothelium is observed under a microscope. After the airbag deployment test, the anterior segment of pig eye including sclera and cornea are cut out and the iris is removed. Trypan Blue and Alizarin Red are applied to the sclerotic corneal in order to stain the area of corneal endothelial cell losses. Microscope images are preserved and areas of cell losses are measured.

Figure 6 is a photograph of the corneal endothelial cells after the airbag deployment. The cell losses are stained darkly. Since the corneal endothelial cell losses cannot be compensated, loss of numerous cells might cause serious corneal endothelial injury.

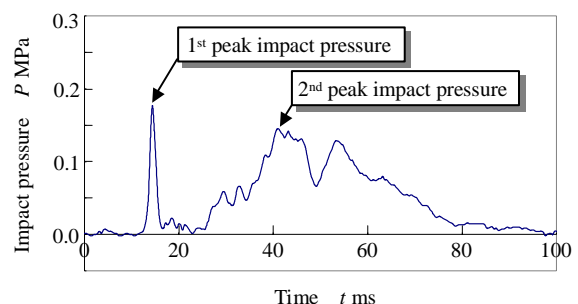


Figure 5. Impact pressure ($d=220\text{mm}$).

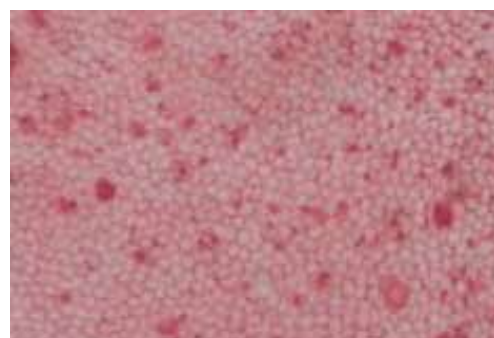


Figure 6. Corneal endothelial cells after test.

Figure 7 shows the relationship between corneal endothelial injury rates and 1st peak impact pressures. The impact pressure value is the average of the 1st peak impact pressures measured by the four load cells surrounding a pig eye. Injury rate is defined as an area ratio between cell losses and normal cells. Figure 7 shows a certain degree of correlation between injury rate and 1st peak impact pressure.

In the case of a normal human eye, the number density of corneal endothelial cells is about 4000/mm². If the density value drops to 400~500/mm² (about 90% or more of the cells are injured), serious injury occurs and the cornea might require penetrating keratoplasty (PKP) [8].

In addition, if injury rate becomes 50% or more, careful management is required in cataract operation. Figure 7 shows that, in consideration of these cases, the airbag deployments we conducted under the conditions of the present fixed plate tests are unlikely to cause serious corneal endothelial injury.

Statistical Investigation

Although a certain degree of relationship between the injury rates and impact pressures is observed, for the sake of closer examination we introduce the risk curve which indicates the probability of injury. The risk curve is used in the estimation procedure used in risk management. The method can quantitatively estimate the results of

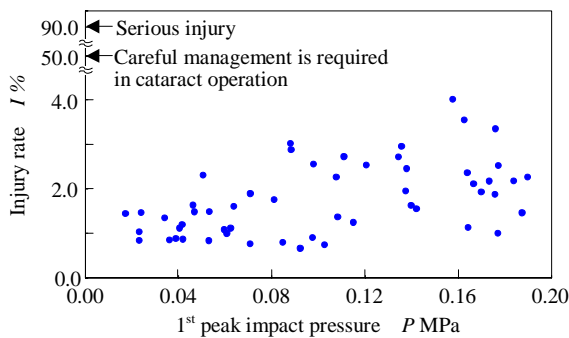


Figure 7. Relationship between corneal endothelial injury rate and 1st peak impact pressure.

multivariate experiments.

Using the data of Figure 7, risk curves are obtained for the ranges of 0.02MPa~0.06MPa, 0.06MPa~0.15MPa and 0.15MPa~0.19MPa. Within each range, all injury rates measured by the tests are rearranged, and the probability k_i of each injury rate is calculated. The excess probability K_i is calculated by substituting k_i into following equations:

$$K_1 = k_1, \quad \text{for } i = 1$$

$$K_i = 1 - (1 - K_{i-1})(1 - k_i), \quad \text{for } i \geq 2 \quad (1).$$

Figure 8 shows the results calculated by Equation 1, wherein the horizontal axis represents injury rate and the vertical axis represents excess probability. In this risk curve, the probability of a high injury rate increases when the plot moves toward the upper right. The area bounded by each risk curve, the vertical axis, and the horizontal axis represents average injury rate.

Figure 9 shows the relationship between average injury rate and 1st peak impact pressure

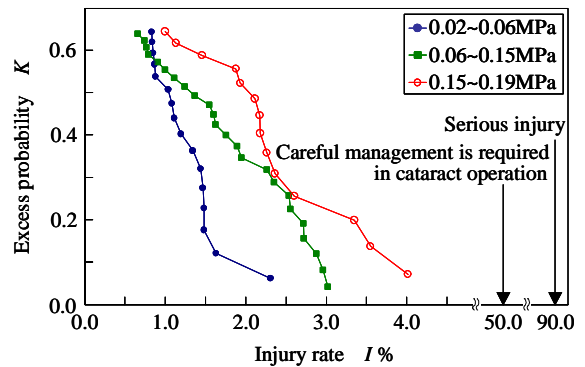


Figure 8. Risk curve.

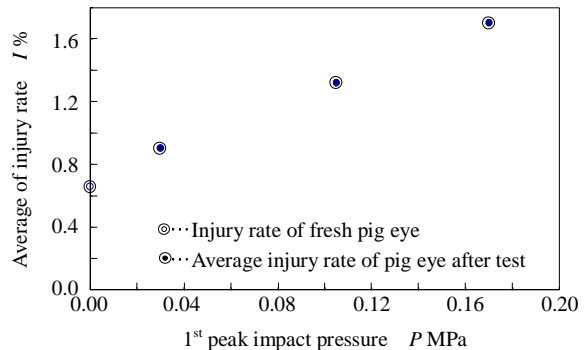


Figure 9. Relationship between average injury rate and 1st peak impact pressure.

obtained by the risk curve (Figure 8). From Figure 9, average injury rate and 1st peak impact pressure are ascertained to have an almost linear relationship. Throughout these tests, maximum impact pressure is about 0.2MPa. This shows that under the conditions employed in the present fixed plate tests, endothelium injury level caused by airbag deployment is low; in other words, serious corneal damage was not observed within the conditions of the present experiments.

INFLUENCE OF FOLDING PATTERN ON IMPACT PRESSURE

In this chapter, we discuss the influence of airbag folding pattern upon airbag performance. Since folding pattern is expected to affect the airbag deployment characteristics, it may also change the value of impact pressure. Deployment tests were conducted for airbags folded in different patterns. The fixed plate was equipped with thirteen load cells, and the impact pressures were measured. The distance d between the steering wheel and the fixed

plate is set as $d=300\text{mm}$.

Figure 10 shows the position of the thirteen load cells for the measurements of impact pressure. The position of the load cell at point “a” coincides with the longitudinal center of the steering column.

Measurements of impact pressure at these thirteen points provide the basis of discussion on the influence of folding patterns. Among various folding patterns, in this chapter, the difference between folding pattern I and folding pattern II is discussed. Figure 11 shows distributions of 1st peak impact pressures obtained from the tests for the two types of folding pattern. Comparison of the two folding patterns shows that the levels of impact pressure are apparently different. We can see that the impact pressure values of folding pattern II tend to be higher than those of folding pattern I.

CONCLUSIONS

In airbag deployment tests under the conditions employed in this study, serious injuries to corneal endothelial cells of pig eyes are not observed. This observation suggests that airbag deployment does not result in serious damage to the corneal endothelium within the condition of the present experiments.

The relationship between ocular endothelial injury rate and the impact pressure caused by airbag deployment is obtained.

The results of experiment also show that impact pressure is influenced by the airbag folding pattern.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Mr. T. Nakao and to Mr. K. Muramatsu.

REFERENCES

1. Maria, Segui (2000). “Driver Airbag Effectiveness by Severity of the Crash”, *American Public Health Association*. Vol.90, No.10, October. pp. 1575-1581.

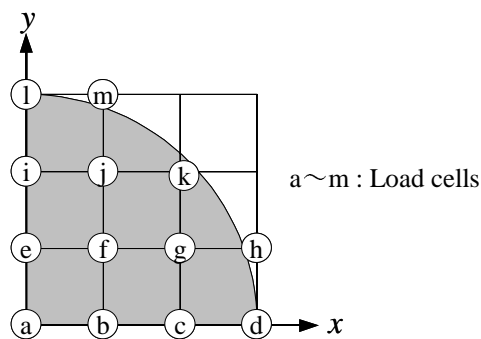
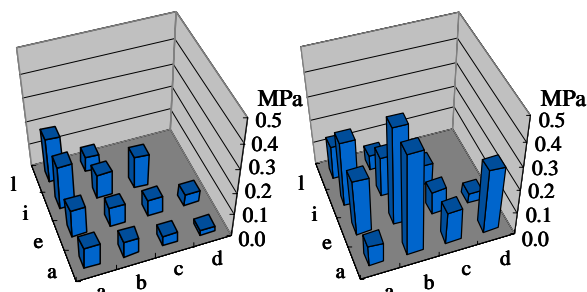


Figure 10. Position of load cells.



Folding pattern I Folding pattern II
Figure 11. Distribution of 1st peak impact pressures.

2. Kisielewicz, L.T. et al. (1998). "Numerical Prediction of Airbag Caused Injuries on Eyeballs After Radial Keratotomy", SAE Paper 980906.
3. Joel A, Pearlman et al. (2001). "Airbags and Eye Injuries: Epidemiology, Spectrum of Injury, and Analysis of Risk Factors", *Survey of Ophthalmology*. Vol. 46, Issue 3, November-December. pp. 234-242.
4. Stefan, M.Duma et al. (1996). "Airbag-Induced Eye Injuries: A Report of 25 Cases", *J Trauma*. Vol.41. pp. 114-119.
5. Gault, J.A. et al. (1995). "Ocular Injuries Associated with Eyeglass Wear and Airbag Inflation", *J Trauma*. Vol.38, No.4. pp. 494-497.
6. Lasher, M.P. et al. (1993). "Corneal edema, hyphema, and angle recession after air bag inflation", *Arch Ophthalmol*. Vol.111. pp. 1320-1322.
7. Kazumi, Fukagawa et al. (1993). "Corneal Endothelium Cell Loss Induced by Air Bags", *Ophthalmology*. Vol. 100, No.12, December. pp. 1819-1823.
8. Toshio, Imaizumi (1994). "Suihousei Kakumakushou no Rinshou" [Clinical findings of bullous keratopathy], *Nihon no Ganka [The Journal of the Japan Ophthalmologists Association]*. Vol. 9. pp. 1033-1037.